Studying Strong Corrections to Weak Interactions using Lattice Quantum Chromodynamics

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A very tiny asymmetry in nature, under the simultaneous application of the charge conjugation and parity operations (CP), can have very dramatic consequences. If there were an equal abundance of matter and antimatter, they would almost completely annihilate leaving behind a radiation-dominated universe today. The observation that our universe is matter dominated and it cannot be explained as a thermal fluctuation requires that the fundamental laws of nature not be symmetric under this interchange of matter and antimatter. In the standard model of particle physics this asymmetry arise due to the Cabibo-Kobayashi-Maskawa phase in the electro-weak sector, but there is no fundamental prediction of its value. Since the smallness of this parameter is not a natural consequence of the structure of the theory, modifications or extensions of the theory can have large effect on CP violating processes. It is therefore essential to determine whether the current experimental observations are consistent with existing theory, or whether they hint at new physics instead.

Neutral K mesons, K^0, and their antiparticles, $\bar{K}^0$, can change into each other, and the experimentally observed mass eigenstates are mixtures of these two. The major effect of CP violating mixing is that the long-lived K_L and the short-lived K_S do not contain equal amounts of K^0 and $\bar{K}^0$ as can be inferred indirectly in their decays. CP violation also manifests itself in the direct decays of K^0 and $\bar{K}^0$ to CP-conjugate states being different. Both direct and indirect CP violations have been accurately measured, and it is now a testable question as to whether both can be explained by the single phase in the standard model.

Even though the fundamental CP violating process is weak and amenable to perturbation theory, corrections due to strong interactions described by Quantum Chromodynamics (QCD) are large. As a result analytical calculation are unreliable.

The major weakness in a complete numerical calculation using lattice QCD is the "quenched approximation," in which the dynamical effects of sea quarks are ignored. Since CP violation arises at very high energies and QCD corrections due to virtual quark loops cannot be neatly separated from other effects. This leads to an ambiguity. Our current calculations (see Fig. 1) demonstrate that results for the quantity ε'/ε describing the ratio between of the direct and indirect CP violating parameters is uncertain by 50%.

Our current calculations are quantifying this last source of systematic error by removing the quenched approximation.

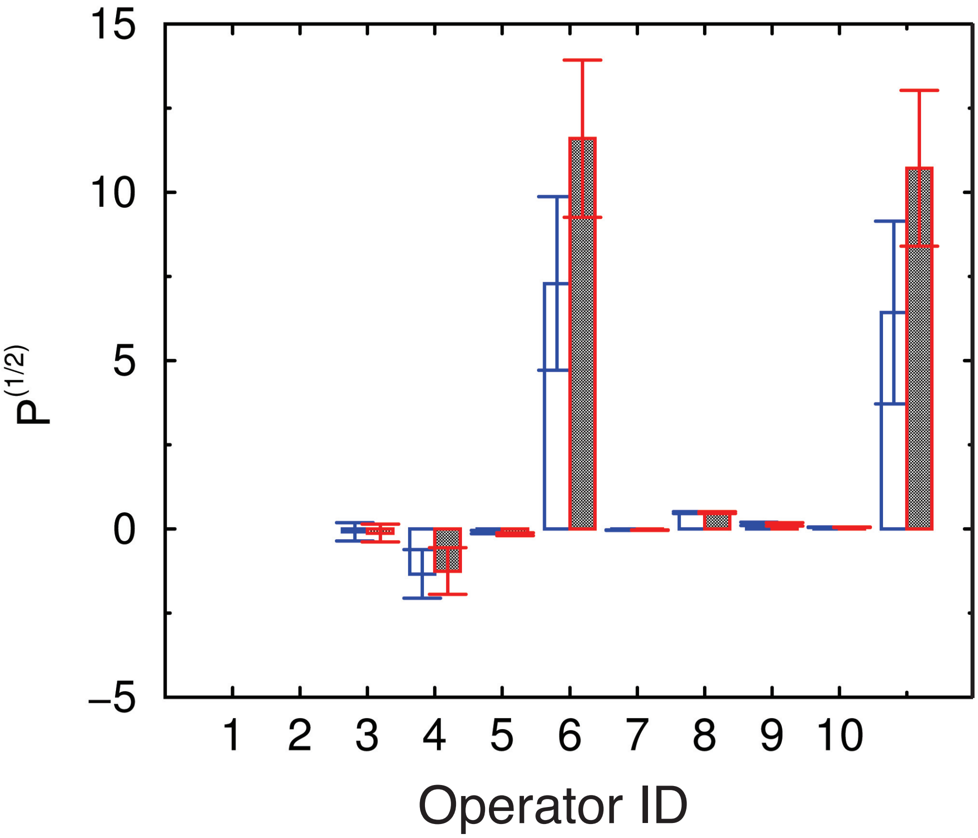

Figure 1—
Contribution to $P^{1/2}$ term of ε'/ε of operators $O^{(1)}$ through $O^{(10)}$, and their sum. The two different lattice discretizations, naïve (empty bars) and Goltermann-Pallante (shaded bars), give results that differ by approximately 50%.